as machinery is probably three hundred times that used as material, and it is here that deficiencies are likely to occur. A crop of 100 bushels of corn per acre will probably require at least 12 inches of water. In the more humid climates a greater amount than this is usually received during the growing season of corn, but the supply is irregular and there are often periods of deficiency of available water. Except where irrigation is possible, the quantity received and the time of its receipt are wholly beyond our control.

The worker in our factory is life, in the plant itself and in the soil bacteria that prepare food for the plant. We can in some cases inoculate the soil with the right kind of bacteria, but beyond that point we are helpless except as we come to the fifth requirement for a factory, namely, favorable working conditions.

Here our opportunity for effective work begins—and ends. We have free material, free power, free machinery, free workers, and the only thing we can do to increase production to any great extent is to improve the working conditions in the soil Ideal conditions would include an optimum supply of water, a well-aerated soil, plenty of food materials, and sufficient heat. It would seem, if we may judge by results, that in the field producing 114 bushels per acre these conditions had been met as far as was humanly possible.

Two things were done in this field that were not done in the 18-bushel field. The soil was stirred to a greater depth and a very large amount of vegetable matter was added. Other experiments have shown that deep tillage without extra vegetable matter is of little or no value, so that the increased yield in this case must have been due to one of two things. Either the abundant supply of humus was entirely responsible, or, in combination with deep tillage, it furnished conditions favoring the highest possible conservation of the water supply, thus stimulating the living workers to maximum activity. Whether or not the deep tillage was of any value remains to be determined by further experiment.

Finally, it appears that effective rainfall is not a function of total rainfall (except when the latter is the limiting factor), but depends entirely upon the condition of the soil and the capacity of the crop for utilizing water. If one were to offer a practical suggestion based on this study it would be this: The addition of what would ordinarily be considered an excessive amount of vegetable matter to the soil might be a very profitable farm practice.

THE WEATHER INFLUENCE ON CROP PRODUCTION IN REGIONS OF SCANTY RAINFALL

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By W. A. MATTICE

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In recent years the surplus of Temperate Zone humid lands suitable for economical cropping has become so small that the possibilities of cropping in semiarid lands have been increasingly studied. Under existing farming practices, the world's food crops are produced on a very small portion of the land. These lie principally in the North Temperate Zone, yet in the Northern Hemisphere outside the Tropics more than three-fourths of the land has an annual rainfall too scanty to permit of successful farming by ordinary methods.

Under such conditions rainfall has a significance not attained in humid regions, because of the fact that at best the moisture present is rarely of a some-to-spare quantity, and what may be termed an average year has barely enough for crops to thrive.

A recent Department of Agriculture Bulletin, No. 1304,[1] entitled "Crop rotation and cultural methods at the Akron, Colo., Field Station," prepared by the Office of Dry-Land Investigations, Bureau of Plant Industry, contains much valuable information relative to crop production in that typical semiarid section of the United States, and a study of the data contained in it brings out many interesting facts as to the weather influence on yields.

In dry-land farming the retention of moisture in the soil is of primary importance, and consequently the relative humidity and the closely associated phenomena of evaporation afford a good index for studying the general effects of weather on crops. Statistical correlations show also that, so far as rainfall is concerned, the amount received during critical periods of growth for the several crops is of much greater importance than the annual amount, notwithstanding a statement in the bulletin above referred to that the greatest single factor in crop production is the amount of annual precipitation. Correlations show that several other factors give much higher coefficients than the annual amount of precipitation.

The minimum amount of precipitation necessary for successful farming by ordinary methods is generally agreed to be between 15 and 20 inches. The Akron station has an average annual amount of 17.95 inches, but this is an average based on only 15 years. More than half of the years had less than this, sometimes reaching as low as 13.44 inches. Although the seasonal distribution of precipitation is in general more or less favorable for crop production, there were years when the amount of moisture received was insufficient to maintain plant growth, and 67 per cent of them had precipitation below normal.

There also occur in this region rather brief droughts which would not appear in a table of monthly totals. While the damage caused by these is difficult to determine and the length of time plants can successfully resist them problematical, their injurious effect is sufficient to aggravate materially the results of the generally scanty moisture supply.

The significance of the evaporation is also difficult to determine quantitatively, but it appears probable that about 1 inch of rainfall is required to offset the effect of 5 or 6 inches of free water-surface evaporation. Griffith Taylor, of the University of Sydney, Australia, found that about 5 inches of evaporation was equivalent to 1 inch of rainfall in Australia (*1*). If this ratio holds true for the United States, the effective rainfall for the summer at Akron, because of the relatively high rate of evaporation, is reduced on the average to about 5 inches.

The Akron, Colo., field station was established in 1907 and the first crops were grown in 1908; the rotations were begun in 1909. The soil at the station is typical of the so-called hard land of that region, and the climate conforms to the general conditions prevailing in the drier parts of the surrounding Great Plains.

Precipitation for the 16 years of record averaged 17.95 inches annually, with an average April to September rainfall of 13.69 inches. The latter is about 76 per cent of the annual, with the greatest monthly amounts occurring from April to August. The temperature is

[1] This bulletin deals entirely with the difference in yields under the various cultural methods and merely touches on the weather effect. The yield data from this bulletin serve as a basis for the correlation studies herein presented.

noticeably affected by the proximity of the mountains, the frost-free season, averaging 140 days, May 12–September 29, being considerably shorter than for lower elevations farther east.

Evaporation measurements were made from April to September, inclusive. The equipment consisted of an open tank 6 feet in diameter and 2 feet deep, sunk to a depth of 20 inches in the ground, with the water level maintained at about the surface of the ground. The average seasonal evaporation is about 42 inches, or over twice the average annual precipitation and nearly three times the amount during the warm season.

In this region, where the amount of moisture received borders on the minimum needed to support cultivated crops, the question of evaporation must necessarily play an important part. The rate of evaporation, however, depends on so many factors that an adequate determination of the amount of moisture lost through this means is extremely difficult to determine. Evaporation from year to year from a free water surface, however, indicates the relative loss from the soil for different years, hence measurements that have been continuous at a given locality and made with the same instruments are comparable when applied to crop yields. The fact that the rate of evaporation correlates closely with the yields of some of the crops will be shown later.

The methods employed in this study to obtain the correlation coefficient follow those used by Smith (*2*) and Wallace (*3*). The first is probably familiar to most readers. Wallace's method supplies means of obtaining a multiple correlation using any number of factors; the maximum employed in this paper is five. The preparations for making the correlations are very simple—the departures from the average yield of the various crops for the period are compared with the various departures of the weather elements. As there are only 15 years of record in this case, an agreement of 12 or more of the departures seemed necessary for obtaining a coefficient enough larger than the probable error to be of value. This was verified to a large extent in the actual working out of the correlations, although exceptions were found where an agreement or disagreement of only 10 or 11 gave a useful value for r.

The crops grown at this station, each by various methods, some of them by as many as 13 to 18, were winter wheat, spring wheat, oats, barley, corn, kafir, milo, and sorgo. Those studied in this paper were the first five. Comparison with the weather elements was made for each method employed in order to determine the method which showed the greatest relation to the weather. Summer fallowing proved to be most baffling but the conclusion was finally reached that the elements which entered into the variations of yield in this case were so varied that any attempt to deal with them all would be beyond the scope of the available data.

The wide variations in the yields of the various crops are very significant—they indicate that about two-thirds of the time the crop is below "normal." The comparatively large crops for one-third of the time raise the general average of the period, so that no idea of the most probable yield is obtained. Thus, if one expects to grow oats in this region without any means of regulating the amount of water for the crop, only one-third of the years will produce a crop worth marketing, as the average yield is so low.

WINTER WHEAT

Winter wheat in Colorado is grown mainly in the northeastern section, where rainfall averages 15 to 20 inches a year, of which about 75 per cent occurs during the six months April to September.

This crop was sown at Akron about September 21, on the average, and was harvested about the middle of July. Table 1 shows the yields of winter wheat (bushels per acre) under eight cropping methods, together with the correlation coefficients between the respective yields and five weather elements.

TABLE 1.—*Winter-wheat yields and correlations*

Method	Yields	Correlation with—				
		June rainfall	Fall rainfall	December mean temperature	June evaporation	Seasonal evaporation
1. Late fall plowing	9. 1	+. 82±. 06	+. 68±. 09	−. 70±. 09	−. 69±. 09	−. 65±. 10
2. Early fall plowing	10. 5	+. 76±. 07	+. 66±. 10	−. 57±. 12	−. 54±. 13	−. 44±. 14
3. Subsoiling	9. 2	+. 83±. 05	+. 74±. 08	−. 66±. 10	−. 69±. 09	−. 58±. 12
4. Listing	10. 1	+. 72±. 08	+. 52±. 13	−. 57±. 12	−. 60±. 11	−. 49±. 14
5. Disking in rotation with corn	13. 5	+. 71±. 09	+. 56±. 12	−. 66±. 10	−. 64±. 10	−. 60±. 11
6. Green manuring with rye.	14. 2	+. 62±. 11	+. 44±. 14	−. 55±. 12	−. 57±. 12	−. 49±. 14
7. Green manuring with peas	10. 8	+. 66±. 10	+. 59±. 11	−. 60±. 11	−. 57±. 12	−. 43±. 14
8. Summer fallowing	19. 1	+. 52±. 13	+. 38±. 15	−. 45±. 14	−. 49±. 14	−. 32±. 16
Mean		+. 70±. 09	+. 57±. 12	−. 60±. 11	−. 60±. 11	−. 50±. 13

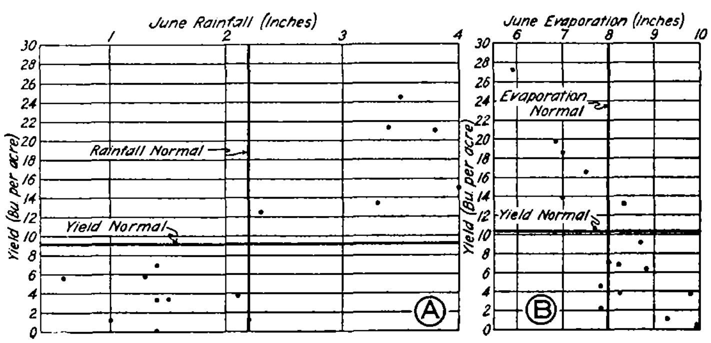

FIG. 1, *A*.—June rainfall and yield of winter wheat 3. *B*.—June evaporation and average spring wheat yield

That the wheat plant must have an abundance of moisture at the time of heading is shown by the occurrence of the highest correlation in the case of yield versus rainfall of the June just preceding harvest. The importance of fall precipitation to development of the root system is also suggested, though it is less than that of the June precipitation. With green manuring and fallowing, June rainfall is not so important. The negative correlations between yield and December mean temperature and June evaporation are most marked in the case of early fall plowing. Seasonal evaporation apparently is of little consequence. From these facts and from figure 1, *A*, we conclude that June precipitation is the dominating factor, and that when it is above normal the winter-wheat crop will also be above normal. The spread of the dots, however, indicates that there are some other factors not taken into account.

The greatest effectiveness of fall precipitation occurs when subsoiling is practiced, enabling the lower soil layers better to retain the autumn rainfall and thus to aid in establishing the good root system so necessary for best growth. June rainfall is more effective with subsoiling and early fall plowing than with any of the other methods—again probably a case of making soil moisture more easily available to the plants.

A multiple correlation was worked out for method 3, or subsoiling, as this seemed to offer the best relation to the weather. The elements used were: (A) June precipitation of the same year; (B) fall precipitation of the year previous, or immediately after planting; (C) the December mean temperature of the previous year; and (D) the June evaporation. The resulting coefficient was 0.94 ± 0.02. This indicates a very good relation between the various elements and the crop, and the regression equation was found:

$$\overline{X} = 1.8A + 2.9B - 0.6C - 1.1D + 33.4$$

Substituting the values of the elements in this equation, we get for the computed yields (bushels per acre):

Year	Computed yields	Actual yields	Difference
1909	25	13	12
1910	11	7	4
1911	3	3	0
1912	18	21	3
1913	7	3	4
1914	20	24	4
1915	21	21	0
1916	4	4	0
1917	9	6	3
1918	0	1	1
1919	11	12	1
1920	18	15	3
1921	5	6	1
1922	4	0	4
1923	5	1	4

Thus, using this formula, the computed yields agree with the actual yields within 1 bushel 40 per cent of the time, within 3 bushels 60 per cent of the time, and within 4 bushels 93 per cent of the time. The large difference in 1909 may be due to the fact that the first croppings came that year and the plants were not able to use the available food. If using the average yield, as is necessary without a definite scheme to base estimates upon, the yields computed must be ± 7 bushels, while using the formula reduces the spread to ± 3 bushels, a reduction of 57 per cent. While the average yield is only 9 bushels, and this probable deviation is a third of it, this is probably as close a result as can be obtained on the basis of only 15 years' record, or without using data more difficult of access.

SPRING WHEAT

The average date of planting spring wheat at Akron was March 29 and the average time of harvesting about the last of July. Table 2 shows the yields of spring wheat (bushels per acre) under 13 cropping methods, together with the correlation coefficients between the respective yields and five weather elements.

TABLE 2.—*Spring wheat yields and correlations*

Methods	Yields	Correlation with—				
		Seasonal evaporation	June evaporation	December mean temperature	June rainfall	May and June rainfall
1. Fall plowed in rotation with corn	11.5	$-.73\pm.08$	$-.76\pm.07$	$-.76\pm.07$	$+.69\pm.09$	$+.72\pm.08$
2. Fall plowed in rotation with oats	8.8	$-.72\pm.08$	$-.78\pm.07$	$-.65\pm.10$	$+.78\pm.07$	$+.75\pm.07$
3. Fall plowed continuous wheat	8.1	$-.74\pm.08$	$-.76\pm.07$	$-.71\pm.08$	$+.71\pm.08$	$+.81\pm.06$
4. Spring plowed in rotation with corn	12.6	$-.77\pm.07$	$-.81\pm.06$	$-.81\pm.06$	$+.76\pm.07$	$+.73\pm.08$
5. Spring plowed in rotation with oats	10.1	$-.76\pm.07$	$-.80\pm.06$	$-.64\pm.10$	$+.74\pm.08$	$+.83\pm.05$
6. Spring plowed continuous wheat	11.5	$-.70\pm.09$	$-.75\pm.07$	$-.74\pm.08$	$+.67\pm.10$	$+.78\pm.07$
7. Subsoiled	7.3	$-.78\pm.07$	$-.79\pm.06$	$-.72\pm.08$	$+.76\pm.07$	$+.77\pm.07$
8. Listed	8.3	$-.77\pm.07$	$-.80\pm.06$	$-.72\pm.08$	$+.74\pm.08$	$+.81\pm.06$
9. Disked in rotation with corn	9.6	$-.77\pm.07$	$-.83\pm.05$	$-.76\pm.07$	$+.82\pm.06$	$+.70\pm.09$
10. Green manured with rye	10.4	$-.73\pm.08$	$-.76\pm.07$	$-.78\pm.07$	$+.72\pm.08$	$+.74\pm.08$
11. Green manured with peas	8.8	$-.76\pm.07$	$-.78\pm.07$	$-.74\pm.08$	$+.75\pm.08$	$+.70\pm.09$
12. Green manured with sweet clover	9.2	$-.72\pm.08$	$-.72\pm.08$	$-.65\pm.10$	$+.59\pm.11$	$+.83\pm.05$
13. Summer fallowed	13.2	$-.74\pm.08$	$-.79\pm.06$	$-.67\pm.10$	$+.78\pm.07$	$+.73\pm.08$
Mean	------	$-.74\pm.08$	$-.78\pm.07$	$-.72\pm.08$	$+.73\pm.08$	$+.76\pm.07$

The greatest single factor in the production of spring wheat appears to be the amount of June evaporation, as shown in Table 2. The amount of spring rainfall has also a very large effect on the yield of spring wheat, probably for the same reason that winter wheat needed rain soon after seeding in order to insure a good root system. The methods which show the greatest relation to June evaporation are disking in rotation with corn and spring plowing in rotation with corn. Evidently the amount of June evaporation has a very decided effect upon the yield. When evaporation was above normal the yield was materially reduced, as indicated by Figure 1, *B*, which shows the relation between June evaporation and the yields of spring wheat, averages of all methods being used in this case.

When the June evaporation was below normal, the yield was above normal five years out of seven, or 70 per cent of the time; and when June evaporation was normal or above, the yield was below normal seven years in eight, or 88 per cent of the time.

As the method of disking in rotation with corn seemed to offer the highest general correlation with the weather, a multiple correlation for this crop and the five elements was worked out. This gave the extremely high coefficient of 0.97 ± 0.01. The regression equation for these elements is:

$$\overline{X} = -0.3A - 0.7B + 0.4C + 0.7D - 0.2E + 37$$

The values of the yields (bushels per acre) computed from this equation are:

Year	Computed yields	Actual yields	Difference
1909	16	15	1
1910	11	13	2
1911	2	1	1
1912	19	15	4
1913	3	6	3
1914	17	12	5
1915	28	21	7
1916	6	6	0
1917	10	14	4
1918	0	6	6
1919	4	6	2
1920	20	13	7
1921	2	4	2
1922	4	6	2
1923	4	7	3

These values give an average deviation from the true yields of 3 bushels. Using the average yield to estimate the crop would not give on the average results closer than 7 bushels, thus a reduction of 4 bushels, or 57 per cent, is effected by the computation. This is probably as close as can be made with the available data.

Figure 2 shows graphically the computed and actual yields. It will be seen from it that the greatest deviations occur in years of greatest yields. It is very evident that there is some variable not included in the data which materially affects the yield, although it would not affect the value of the correlation coefficient to any great extent.

One point of interest in connection with correlations of spring wheat shown in Table 2 is suggested. Why the December mean temperature of the previous year gave a high value for the correlation coefficient is not readily apparent, and in order to verify this as much as possible a correlation between the December mean temperature and the yield of spring wheat was made for the State of North Dakota. The value of r obtained from this was 0.04 ± 0.09, which indicated no relation. For northwestern Kansas, using only one station, as the spring-wheat region is fairly limited there, a value of -0.40 was obtained. This latter value indicates a slight relation between the December mean temperature and the spring wheat yields, although there is no relation in North Dakota. The results at Akron might, of course, be entirely accidental, which seems the logical explanation.

OATS

Oats were sown on the average on April 3 and were harvested about the last of July. Table 3 shows the yields of oats (bushels per acre) under 18 cropping methods, together with the correlation coefficients between the respective yields and six weather elements.

TABLE 3.—*Oat yields and correlations*

Methods	Yields	Correlations with—					
		June mean temperature	June to August mean temperature	June rainfall	February to April relative humidity	June and July evaporation	June evaporation
1. Fall plowed in rotation with wheat	19.8	−0.58±0.12	−0.66±0.10	+0.65±0.10	+0.52±0.13	−0.78±0.07	−0.70±0.09
2. Fall plowed in rotation with oats	21.4	−.65±.10	−.77±.07	+.68±.09	+.74±.08	−.70±.09	−.64±.10
3. Fall plowed in rotation with barley	22.0	−.63±.10	−.72±.08	+.72±.08	+.49±.14	−.72±.08	−.70±.09
4. Spring plowed rotation with wheat	22.7	.58±.12	−.71±.08	+.66±.10	+.76±.07	−.82±.06	−.74±.08
5. Spring plowed rotation with oats	22.6	−.72±.08	−.77±.07	+.66±.10	+.76±.07	−.79±.06	−.75±.08
6. Spring plowed rotation with corn	25.4	−.64±.10	−.81±.06	+.76±.07	+.66±.10	−.86±.04	−.81±.06
7. Subsoiled	20.7	−.70±.09	−.80±.06	+.72±.08	+.51±.13	−.72±.08	−.70±.09
8. Listed	21.2	−.67±.10	−.75±.08	+.73±.08	+.72±.08	−.74±.08	−.72±.08
9. Sod breaking with alfalfa	13.7	−.59±.11	−.74±.08	+.82±.06	+.69±.09	−.84±.05	−.79±.06
10. Sod breaking with bromegrass	11.5	−.39±.15	−.56±.12	+.91±.03	+.65±.10	−.88±.04	−.83±.05
11. Disked in rotation with corn	24.2	−.62±.11	−.72±.08	+.79±.06	+.63±.10	−.84±.05	−.83±.05
12. Disked in rotation with sorgo	16.4	−.55±.12	−.71±.08	+.76±.07	+.64±.10	−.87±.04	−.83±.05
13. Disked in rotation with milo	20.7						
14. Disked in rotation with kafir	19.0	−.62±.11	−.79±.06	+.81±.06	+.67±.10	−.90±.03	−.85±.04
15. Green manured with rye	25.4	−.65±.10	−.76±.07	+.66±.10	+.66±.10	−.81±.06	−.79±.06
16. Green manured with peas	21.7	−.62±.11	−.75±.08	+.79±.06	+.66±.10	−.86±.04	−.85±.04
17. Green manured with sweet clover	20.2	−.63±.10	−.74±.08	+.63±.10	+.78±.07	−.85±.05	−.75±.08
18. Summer fallowed	31.8	−.74±.08	−.76±.07	+.74±.08	+.76±.07	−.87±.04	−.85±.04
Mean		−.62±.11	−.74±.08	+.73±.08	+.66±.10	−.82±.06	−.77±.07

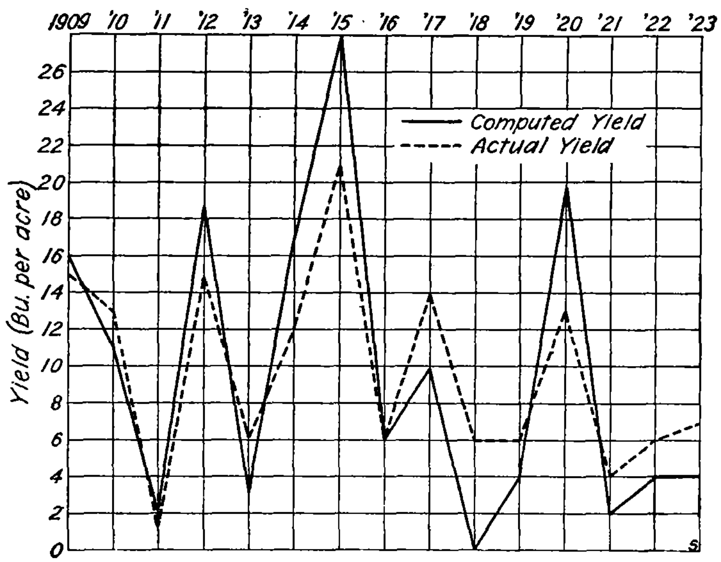

FIG. 2.—Computed and actual yields—spring wheat 9

The fallowed crop here again showed the greatest yields, while those following sod breaking showed the poorest, probably due to the fact that sod soil is mostly dry.

Smith found for oats that when the crop was forming heads cool and moderately wet weather favored the best yields. As will be seen from Table 3, the highest single factor in the growth of oats is the amount of evaporation during June and July. The correlation coefficient for these two months are much higher than any of the others. The other factors in order of importance are June evaporation and the June to August temperature. June rainfall has also a large effect on the yield. A significant thing is the high value of the evaporation correlations.

It would seem that without special cultural practices to maintain soil moisture the extremely high relative evaporation, in relation to the rainfall, would practically prevent the growth of a good crop unless some form of irrigation were carried out to supply the moisture that would normally be lost by this means.

Two multiple correlations were worked for these methods, one with oats 9 and the other with oats 10. In each case only two variables with the yield were used—the amount of June and July evaporation and the June rainfall. The values of the multiple coefficients for these were 0.88 ± 0.04 and 0.95 ± 0.02, respectively.

For oats 9 (fig. 3, *A*) the value of the June and July evaporation gave the best results. Every time the evaporation was above the normal the yield was below normal, but when the evaporation was below normal the yield was above normal only 67 per cent of the time.

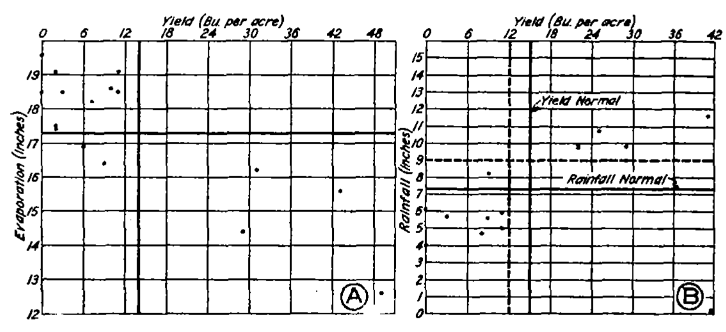

FIG. 3, *A*.—June and July evaporation and yield of oats 9. *B*.—May to July rainfall and yield of corn 8

This would seem to indicate that there might be some other moderating factor when the evaporation was below the average, but that when above average the evaporation was practically the only cause precluding a yield above the average. The June rainfall had somewhat the same effect. When it was below the average the yield was always below, but when the rainfall was greater than the average the yield was greater only 67 per cent of the time. The combined effect of these two factors, with a coefficient of only 0.88 ± 0.04, was not considered sufficiently high to work out the regression equation for the yields, especially in view of the comparative shortness of the record.

With oats 10, however, the effect of the evaporation was much more marked—when evaporation was above normal, yield was below normal 100 per cent of the time, and when evaporation was below the yield was above the average 83 per cent of the time. This in itself indicated the large effect that the evaporation has on crop yields at this place.

The June rainfall combined with the June-July evaporation gave a correlation coefficient of 0.95 ± 0.02, sufficiently large to justify computing the regression equation:

$$\overline{X} = 7A - 3.1B + 50.2$$

The results of computing the yield are:

Year	Computed yields	Actual yields	Difference
1909	24	20	4
1910	3	2	1
1911	0	0	0
1912	29	28	1
1913	6	2	4
1914	24	35	11
1915	38	35	3
1916	6	0	6
1917	0	3	3
1918	0	0	0
1919	7	2	5
1920	30	31	1
1921	2	4	2
1922	6	3	3
1923	13	9	4

The reduction in the standard deviation for these computations was 69 per cent. The largest difference between the computed and actual yields was that for 1914, and, with this exception, the agreements were within 6 bushels. The agreements on the large yields are, with the above exception, all very close, indicating that years with large yields were more nearly related to the weather factors than the others. The computed values agree, on the average, within 4 bushels, while the value of the standard deviation for the actual yields is 13.5 bushels. As the deviation of the computed yields from the actual is only one-third as great as the standard deviation of yield, a considerable improvement is affected.

There are undoubtedly other factors which would bring the correlation closer, but they are probably so numerous that a correlation including them would be cumbersome and tedious.

BARLEY

Barley was planted at Akron on April 6, on the average, and matured about the last of June or the first of July. Table 4 shows the yields of barley (bushels per acre) under seven cropping methods, together with the correlation coefficients between the respective yields and five weather elements.

TABLE 4.—*Barley yields and correlations*

Methods	Yields	Correlations with—				
		June mean temperature	February to June relative humidity	June rainfall	May and June rainfall	June and July evaporation
1. Fall plowed	18.0	−.53±.13	+.73±.08	+.66±.10	+.67±.10	−.67±.10
2. Spring plowed	17.1	−.58±.12	+.77±.07	+.66±.10	+.78±.07	−.76±.07
3. Spring plowed following oats	20.1	−.62±.11	+.80±.06	+.69±.09	+.83±.05	−.82±.06
4. Subsoiled	15.5	−.61±.11	+.80±.06	+.81±.06	+.71±.08	−.85±.05
5. Listed	18.6	−.69±.09	+.79±.06	+.71±.08	+.77±.07	−.81±.06
6. Disked following corn	20.8	−.60±.11	+.78±.07	+.76±.07	+.75±.08	−.85±.05
7. Summer fallowed	30.9	−.69±.09	+.81±.06	+.65±.10	+.72±.08	−.80±.06
Mean		−.62±.11	+.78±.07	+.71±.08	+.75±.08	−.80±.06

The fallowed crop gave the highest average yield, as was the case with the other grains. The yields did not vary so greatly from the average as most of the others but they were below the average about two-thirds of the time. The average yields, however, were higher in general.

The most important factor for barley at Akron is the June and July evaporation, with an average value of the correlation coefficient of -0.80 ± 0.06. The February to June relative humidity plays an important part, with a coefficient of 0.78 ± 0.07, and the May and June rainfall gave a value of 0.75 ± 0.08.

A multiple correlation with barley 3, by using (A) June and July evaporation, (B) the February to June relative humidity, and (C) the May to June rainfall, gave a coefficient of 0.92 ± 0.02 and the regression equation:

$$\overline{X} = -2.7A + 0.2B + 2.7C + 37.8$$

The computed and actual yields are given below:

Year	Computed yields	Actual yields	Difference
1909	20	22	2
1910	8	10	2
1911	0	2	2
1912	18	35	17
1913	10	8	2
1914	20	40	20
1915	39	50	11
1916	10	6	4
1917	23	33	10
1918	7	3	4
1919	10	18	8
1920	27	29	2
1921	4	8	4
1922	16	16	0
1923	24	20	4

The greatest deviations from the actual yield occur for the years of greatest yields. There is evidently some unconsidered factor which would make closer agreement for these years.

CORN

Corn was planted at Akron about May 17, on the average, and probably matured the last of August or the first of September. Table 5 shows the yields of corn (bushels per acre) for 13 cropping methods, together with the correlation coefficients for three weather elements.

TABLE 5.—*Corn yields and correlations*

Methods	Yields	Correlations with—		
		May to July rainfall	June and July evaporation	June to August mean temperature
1. Fall plowed in rotation with oats	13.6	+.74±.08	−.82±.06	−.74±.08
2. Fall plowed in rotation spring wheat	13.3	+.89±.03	−.82±.06	−.80±.06
3. Fall plowed in rotation winter wheat	12.5	+.90±.03	−.82±.06	−.77±.07
4. Fall-plowed continuous corn	17.9	+.82±.06	−.79±.06	−.68±.09
5. Spring-plowed rotation oats	13.6	+.89±.03	−.86±.04	−.73±.08
6. Spring-plowed rotation barley	15.8	+.80±.06	−.83±.05	−.72±.08
7. Spring-plowed rotation spring wheat	14.5	+.88±.04	−.81±.06	−.75±.08
8. Spring-plowed rotation winter wheat	15.5	+.89±.03	−.77±.07	−.75±.08
9. Spring-plowed continuous corn	17.6	+.71±.08	−.64±.10	−.59±.11
10. Subsoiled	16.2	+.83±.05	−.69±.09	−.64±.10
11. Fall listed	15.6	+.45±.14	−.40±.15	−.22±.17
12. Spring listed	13.9	+.54±.12	−.58±.12	−.33±.16
13. Summer fallowed	23.1	+.69±.09	−.42±.15	−.43±.14
Mean		+.77±.07	−.71±.08	−.63±.10

The results with corn are the most unsatisfactory of all the crops grown at this station. As shown in Table 5, the first seven or eight methods apparently are more affected by the weather than the last five or six.

The amount of May to July rainfall seems more important in this case than evaporation, the values of r being consistently higher than any correlations with evaporation.

If the May to July rainfall is not at least about 9 inches, or 2.3 inches above the average, the yield of corn is not above average. This is shown for corn 8 in Figure 3, *B*, where the heavy horizontal and vertical lines represent, respectively, the averages of the corn and rainfall data; the broken lines represent the apparent limits of the corn yield and rainfall. If the normals were transposed to the new positions there would be a perfect agreement between the dots and the normal lines. The corn yield would be below normal every time the rainfall was below, and vice versa. The rather close grouping of the dots indicates a close relation between this factor and the yield, although there is still some spread.

A multiple correlation computed for corn 2 and the variables, June and July evaporation, May to July rainfall, and June to August mean temperature, gave a correlation coefficient of 0.92 ± 0.02, and the regression equation:

$$\bar{X} = -2A + 2B - 2C + 173$$

The computed yields gave a standard deviation from the actual yields of 4.0, or a reduction in the standard deviation of yield of 65 per cent. The values of the computed and actual yields are given below:

Year	Computed yields	Actual yields	Difference
1909	19	22	3
1910	3	6	3
1911	0	6	6
1912	31	32	1
1913	5	0	5
1914	11	7	4
1915	33	31	2
1916	5	0	5
1917	19	13	6
1918	7	9	2
1919	5	4	1
1920	31	35	4
1921	5	6	1
1922	11	10	1
1923	21	17	4

The standard deviation, 4 bushels, is less than a third of the average yield for this method, which shows the value of the equation for computing purposes. A multiple correlation with corn 3 gave a value of 0.93 ± 0.02; this was so close to the value obtained for corn 2 that no regression equation was computed.

The computed yields give a standard deviation from the actual yields of 5.3 bushels, or a reduction of 54 per cent from the standard deviation of yields. There are some large variations, but on the whole the agreements are quite close.

It is evident from the foregoing that in regions of scanty rainfall the amount of precipitation during the critical period of growth is the determining factor in the growth of corn.

Corn 8 showed such close relation between the yield and the May to July rainfall, as shown in Figure 3, *B*, that a regression equation for these two variables was computed, as follows: $y = -16.9 + 4.3r$. The values of the computed yields from this equation were as follows:

Year	Computed yields	Actual yields	Difference
1909	25	22	3
1910	5	11	6
1911	0	0	0
1912	26	29	3
1913	7	9	2
1914	12	12	0
1915	22	29	7
1916	9	0	9
1917	26	22	4
1918	8	11	3
1919	8	3	5
1920	33	41	8
1921	3	8	5
1922	18	9	9
1923	29	25	4

SUMMARY

The general climatic features of this region make the amount of seasonal or annual precipitation the limiting factor for successful crop production. Regions of less variability of precipitation generally produce larger crops and also have smaller variations in the yields.

In regions of generally adequate summer precipitation, Ohio, for example, winter wheat averages 18 bushels to the acre, while at Akron the average is only 12.8. Spring wheat averages 15.6 bushels per acre in Ohio, but only 10.3 at Akron. Oats in Ohio average 37.8 bushels per acre; at Akron, only 22.4. Barley was 28.4 bushels in Ohio and only 20.3 at Akron. Corn shows plainly the difference in results where generally adequate moisture prevails and where it is only barely sufficient at best. In Ohio it averages 38.9 bushels; at Akron, 14.6. These averages for Ohio, it must be remembered, are for the whole State, while at Akron they are for a limited area and produced under the very best cultural methods known to science and under constant and direct supervision of highly trained agriculturists. From these few data it will be seen that the moisture, while it is evidently of major importance at Akron, is probably not the most critical factor in more humid regions.

This study indicates that growing dry-land crops under conditions such as exist at Akron is decidedly precarious—and this holds for large areas of the drier sections of the United States. Of the five crops considered in this paper winter wheat alone showed an even chance of giving an average yield; it varied above normal eight times and below seven. Spring wheat and corn averaged above normal 40 per cent of the time, while oats and barley averaged above normal only 33 per cent of the time.

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